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MULTICS SECURITY EVALUATION: PASSWORD AND FILE ENCRYPTION TECHN--ETC(U)
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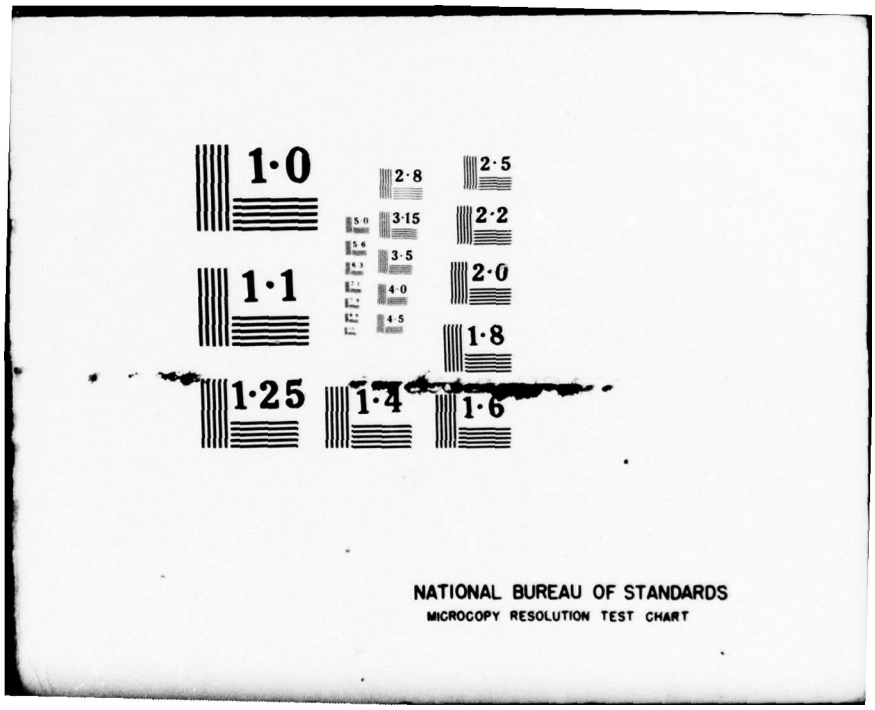
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ESD-TR-74-193, Vol. III

MULTICS SECURITY EVALUATION: PASSWORD AND FILE ENCRYPTION TECHNIQUES

Deputy for Command and Management Systems

June 1977

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Prepared for

DEPUTY FOR COMMAND AND MANAGEMENT SYSTEMS
ELECTRONIC SYSTEMS DIVISION
HANSCOM AIR FORCE BASE, MA 01731

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Multics
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Protection
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Secure Computer Systems
Security Penetration
Security Testing

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Passwords are stored in enciphered form in the Multics system. There is no clear text listing of the password file. In 1972, as part of a security analysis of Multics, an ESD team successfuly inverted the enciphering algorithm in use on Multics. This report documents the team's efforts. As a result of the ESD analysis, an improved encryption algorithm is now in use on Multics.

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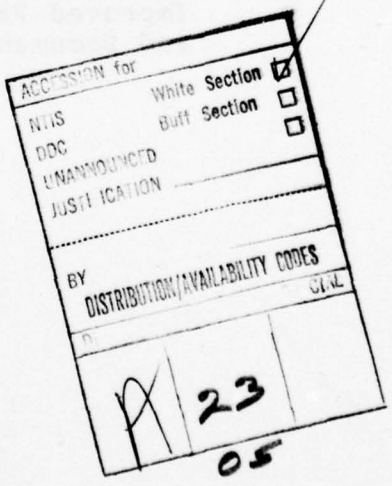
PREFACE

This is Volume 3 of a 4 volume report prepared for the Air Force Data Services Center (AFDSC) by the Directorate of Computer Systems Engineering, Deputy for Command and Management Systems, Electronic Systems Division (ESD/MCI). The entire report represents an evaluation and recommendation of the Honeywell Multics system carried out under Air Force Project 6917 from March 1972 to June 1973. Work described in this volume was performed by personnel at ESD/MCI with support from the MITRE Corporation. Computer facilities at the Rome Air Development Center and the Massachusetts Institute of Technology were used in the evaluation effort. This volume was primarily authored by 1Lt Peter L. Downey. Additional inputs to the text made by James P. Anderson and Captain Brian W. Woodruff. The programs in Appendices B and C were written by Capt Paul Karger. The algorithm for "better" was developed by Lt Col Roger Schell, who also wrote the program in Appendix D.



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SECTION I
INTRODUCTION

1.1 Basis for the Study

The Multics system <ORG71> began at the Massachusetts Institute of Technology (MIT) in 1964 with the objective of producing a computer utility embracing the whole complex of hardware, software and users to serve as a model for other similar systems. The impetus for Multics came from the successful Compatible Time Sharing System (CTSS) that had been developed at MIT previously on the IBM 709 and 7094.

The Multics system, because of its ambitious objectives of serving as a prototype utility was concerned at the outset with protection issues clearly in mind. The specific mechanisms designed to permit sharing of various objects (i.e. programs, data etc.) safely are discussed in <GRA68>, <SCH72a>, and <SCH72b>.

In response to a requirement for "advanced" interactive and multilevel processing imposed by the USAF and other DOD customers in the Pentagon, the Air Force Data Services Center (AFDSC) identified the Honeywell Multics system as a computer system that could meet the requirements. Because of the multi-(security)level processing ancitipated, AFDSC commissioned the Electronic Systems Division (ESD) of the Air Force Systems Command to conduct a security analysis of Multics to ascertain whether the system could indeed provide multilevel secure processing in a "benign" (restricted access) environment where all users have at least a Secret clearance and some users have a Top Secret clearance. As a result of ESD's security analysis, Honeywell has implemented security enhancements to the Multics operating system to support AFDSC's requirements. <WHI73>

As part of the security analysis, penetration attacks were organized and tested on the Multics systems at MIT and at the USAF's Rome Air Development Center. Volume II of this report <KAR74> describes the results of the penetration attacks. Volume III reports in detail on one accomplishment of the penetration exercise, namely, the successful inverting of the "non-invertible" password enciphering algorithm which was used in Multics at the time of the penetration in 1972 and 1973. The relative ease with which the Multics password enciphering algorithm was broken is instructive in showing the care with which a password or file enciphering algorithm must be chosen. It is an example of how easily one can be misled regarding the

"non-invertibility" of an algorithm. The method of analysis exploits some simple methods of number theory, and points out the general approach taken in such an analysis.

1.2 Why Scrambled Passwords?

The login password file of any system presents an attractive and tempting target for would-be penetrators of time sharing systems. Such files have been the primary target of numerous penetration exercises, because with the information contained in them a penetrator can masquerade indefinitely and effectively for long term exploitation of a system.

For the reasons outlined in <KAR74>, obtaining the password file internally from the system is of minimal value to a penetrator who is also an authorized user of the system. However, for a penetrator who may not always be an authorized user of the system, obtaining a user's password is of great value. In addition, passwords might appear in memory dumps. Therefore, password files need to be protected.

The special vulnerability of a list of passwords and owners to attack by penetrators was recognized by R.M. Needham <WIL72> who proposed the idea of storing the ciphertext of an encrypted password with the owner's identification. He proposed that the cipher transformation be 'one-way', that is, for this particular use, there is no need to have a reversible transformation (the usual case for cryptographic applications). The reasoning behind Needham's proposal was that even if the file of encrypted passwords and their user identifiers was compromised, it would be impossible to ascertain the user's input password and thus masquerading would be prevented.

Evans et. al. <EVA74> elaborates somewhat on Needham's proposal and discusses, in a heuristic way, families of password scrambling functions. The interesting part of that paper is the observation that some of the primitive scrambling functions must be non-linear in order to defeat analytic attacks on the algorithms. In general, Evans has covered the major considerations involved in using one-way ciphers for password protection.

The scheme used to scramble passwords on Multics was devised prior to and independently of the considerations outlined by Evans (or in the related papers by Purdy <PUR74> or Johnson <JOH74>).

1.3 The Multics Password Scrambler

In the Multics system, user passwords are protected by storing the encrypted version of the password in a segment known as the Person Name Table (PNT). This is the only form in which a password list is maintained in Multics. No clear text listing of passwords exists anywhere in the system. The PNT is further protected from unauthorized access by the contents of its Access Control List (ACL).

The one-way cipher scheme used in Multics is called scramble_. A PL/1 listing of the routine appears in Appendix A.

The Multics scrambler works by first compressing the 8 Multics-ASCII character password from 72 to 56 bits by removing the high-order two bits (always zero in the 9 bit Multics representation of 7 bit ASCII characters) from each character. If the password is less than 8 characters in length, blanks were added to make it 8 characters long. The resulting compressed password, called p, is then multiplied by its own low-order 16 bits, then reduced modulo 10**19-1.

The notation

(1) R = mod(D, C) means

(2) D = C*Q+R

with

(3) $0 \leq R < C$

and C, D, Q, and R are all non-negative integers. Define

(4) a = mod(p, 2**16)

Then the compressed password conversion to r, the number stored in the PNT, is given by

(5) r = mod(p*a, 10**19-1)

Two attacks on this "non-invertible" function were developed. These are discussed below.

SECTION II
TRAILING BLANKS ATTACK

If it is assumed that most passwords are less than or equal to 6 non blank characters in length (the human lassitude hypothesis), they can be brute force decrypted very rapidly.

Scramble_ left justifies the ASCII input characters in the 8 character field before encryption. As a result, a password whose length is less than or equal to 6 characters contains trailing blanks (octal 040) which when compressed create a p of the form:

p=b(56), b(55), b(54).....b(18), b(17), XX 0100000 0100000

where the b(i) denotes arbitrary bits and each X can be either 0 or 1. On inspection there are only four possible lower 16 bit patterns:

a(1) = 00 0100000 0100000

a(2) = 01 0100000 0100000

a(3) = 10 0100000 0100000

a(4) = 11 0100000 0100000

From (2) we observe, where Q is the integer part of D/C,

(6) Q = floor(D/C).

Letting c = 10**19-1, from (5) we have r = mod(p*a, c).

Applying (1) and (2) we obtain

(7) p*a = c*q+r, where q is a non-negative integer.

In the special case of trailing blanks, we are attempting to find p in (7), given r (the encrypted value of p from the PNT), c (10**19-1), and the only four possible values of a. In attempting a brute force decryption by trying all possible values of q for each of the possible values of a, the only deterrent is the maximum value q can obtain from (7). The maximum value of q determines the maximum number of trials that would be required.

We can determine the maximum value of q by noting that

(8) $q = (p*a-r)/c \leq p*a/c$

By definition of a, we have

(9) $a < 2^{**}16$

Similarly, we have

(10) $p < 2^{**}56$ and

(11) $c < 2^{**}64$ (i.e. $10^{**}19 < 2^{**}64$)

then

(12) $p*a/c < (2^{**}16)\ (2^{**}56)/2^{**}64$

$< 2^{**}72/2^{**}64$

$< 2^{**}8$

The significance of this result is that a is so small that only a little over 250 trials are required to determine p.

A brute-force algorithm unscr (r, a, p) was created which finds a valid password, p, which corresponds to the encrypted value, r, provided a = low order 16 bits of p. Figure 1 is a flowchart for unscr. (A listing for unscr appears in Appendix B). The unscr subroutine was applied to a PNT which contained 1082 entries. Unscr either printed a recovered password, or reported a failure (passwords > 6 characters long). Figure 2 depicts the cost in CPU time of this program on the 1082 entries. Sixty-two percent of all of the passwords on the MIT Multics system were thus obtained with little effort. The figure shows the cost in CPU time to recover short passwords was minimal.

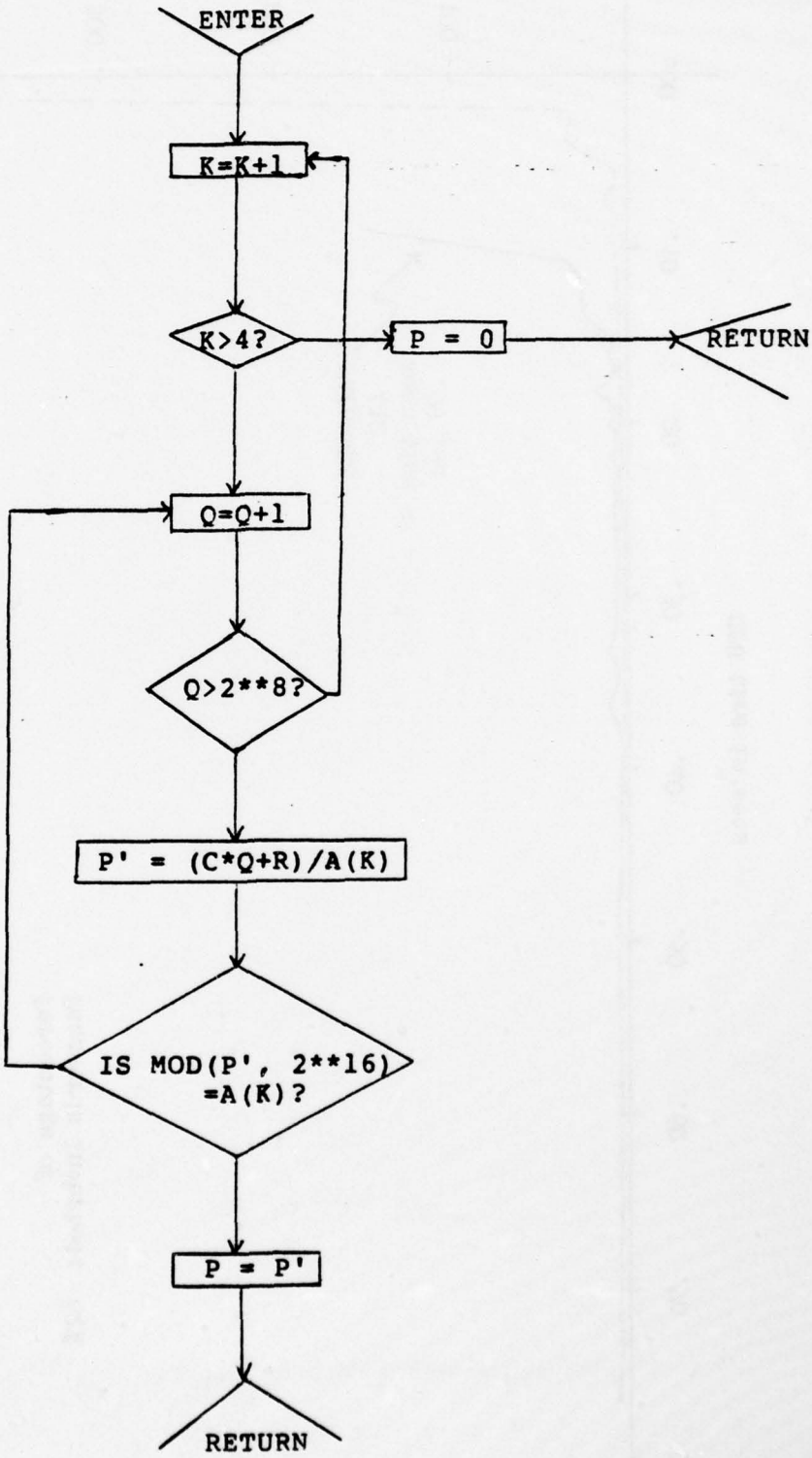

FIGURE 1. Flowchart for unscr.

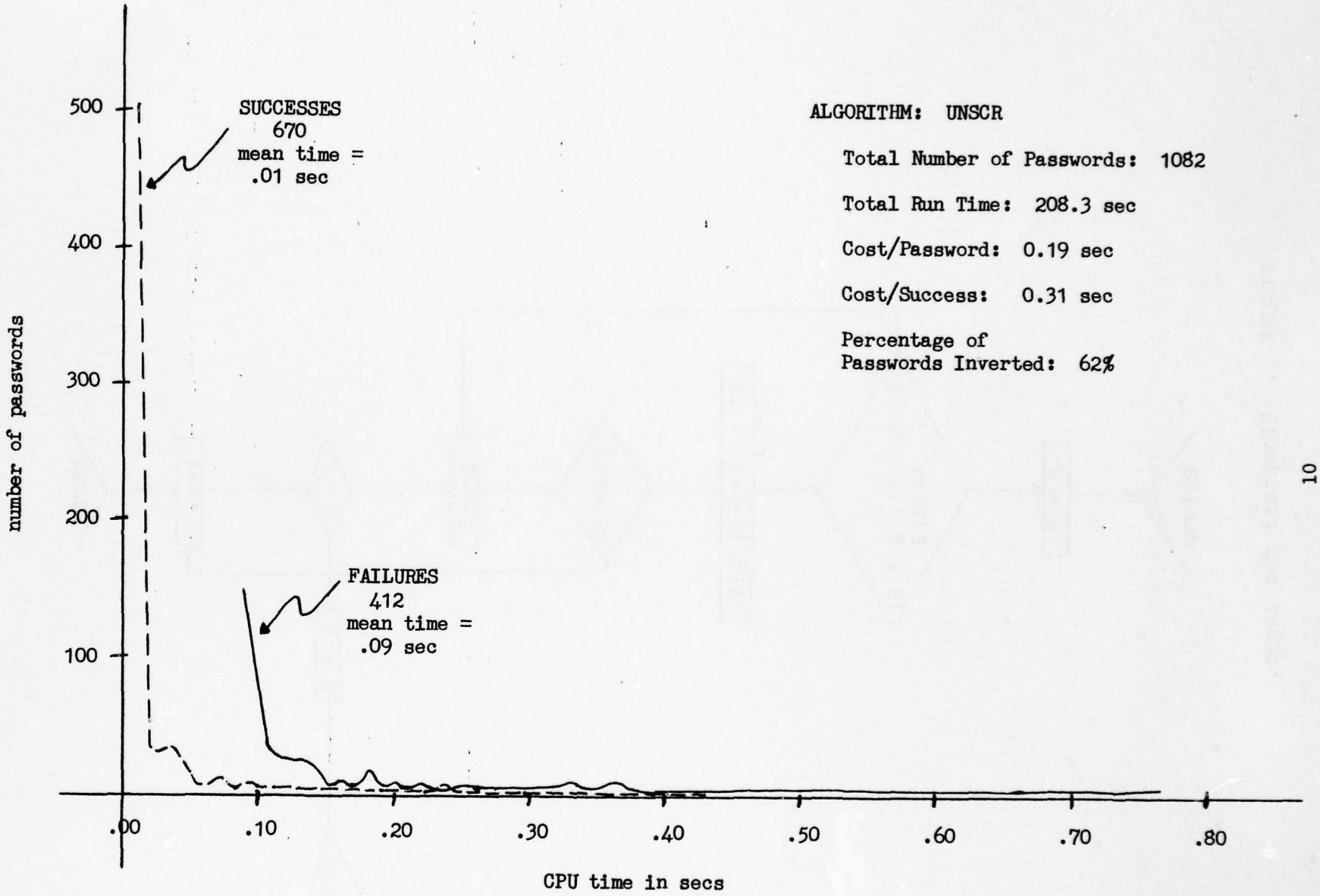

FIGURE 2. Cost in CPU time to either successfully invert a password or to report a failure

SECTION III
GENERAL SOLUTION

Having developed a solution for a special case, it was of some interest to determine whether or not a general solution could be obtained. Such a solution was found; it was based on the observation that the low order 16 bits of p*a (the immediately transformed password (56 bits)) are identical to a*a.

Call the low order 16 bits of p*a, d. Then,

(13) d = mod(p*a, 2**16)

Let p = x*(2**16) + a, where x is an integer. Then,

(14) d = mod((x*2**16 + a)*a, 2**16)

= mod(x*a*2**16, 2**16) + mod(a*a, 2**16)

= 0 + mod(a*a, 2**16)

= mod(a*a, 2**16)

Let the function mod(a*a, 2**16) = g(a). Then let h(d) denote the inverse of the function g. That is, h(d) denotes the list of all of a, ($a \leq$ 2**16), with g(a) = d.

The general decryption algorithm was called better. Better first generates a two-part table. Part I contains possible values of d and a pointer. The pointer is either a null pointer (if h(d) is empty), or it is a pointer to a value of h(d) in part 2 of the table.

The interesting aspect of h(d) is the fact that it is quite sparse; consequently it has the potential for rapidly discriminating whether or not a hypothesized inversion (of a password) is correct.

To illustrate what is meant by h(d) being sparse, consider an example in base 10:

a	g(a) (mod 10)	a	g(a) (mod 10)
0	0	5	5
1	1	6	6
2	4	7	9
3	9	8	4
4	6	9	1

Then h(d) is given by:

d	h(d)	d	h(d)
0	0	5	0
1	1,9	6	4,6
2	null	7	null
3	null	8	null
4	2,8	9	3,7

In this simple example, only six out of ten possible values of d would need to be considered further in an attempt to unscramble a password.

Figure 3 is a flowchart for better. A listing of better is in Appendix C.

The procedure better was run on a PNT of 1085 names. The following CPU run times were recorded.

Table generation	200 sec
Inverting Passwords	148 sec
Total Time	348 sec
Cost/Password	0.32 sec

Note that the cost figure is comparable to that for the special case decryption based on trailing blanks. On a larger PNT, the average cost would be less since the cost of the d and h(d) table generation is constant.

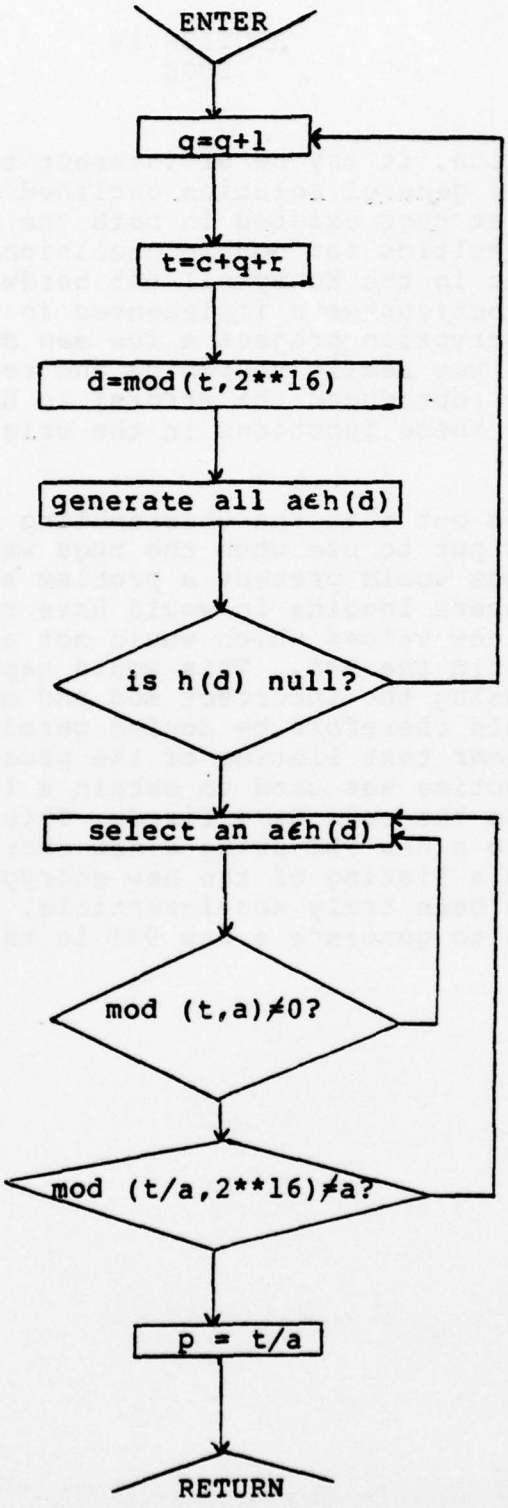

FIGURE 3. Flowchart for better.

SECTION IV
BUGS

As an aside, it may be of interest to note that in developing the general solution outlined above, it was discovered that bugs existed in both the mod and multiply functions in Multics for double precision integers. Because of limitations in the Honeywell 645 hardware instruction set, these functions were implemented in software. This caused the decryption project a few man days of effort to diagnose what was really happening and required special code (that exactly reproduced the errors) to handle the bugs introduced by these functions in the original scrambling function.

It turned out that the unscrambling routine which was developed was put to use when the bugs were fixed. Simply fixing the bugs would present a problem since after the bugs were fixed, users logging in would have their passwords scrambled to new values which would not agree with the values listed in the PNT. This would happen because the PNT was created using the incorrect mod and multiply functions. The users would therefore be denied permission to log in. Because no clear text listing of the passwords existed, the unscramble routine was used to obtain a listing of all user passwords when the bugs were fixed. This listing was then converted into a new PNT using a new encryption routine. Appendix D is a listing of the new encryption routine. If scramble_ had been truly non-invertible, it would not have been possible to generate a new PNT in this fashion.

SECTION V
CONCLUSION

Password encryption is not a fundamental requirement for providing security in a computer system. As discussed previously, if a penetrator is able to access the password file in a computer, he is most likely able to access any other file in that system as well, and the knowledge of users' passwords would be of little value to him.

In addition, it is generally unnecessary to access a password file from the system in order to obtain a user's password. Obtaining a user's password may be as simple as copying it from some place where the user has written it. Even if the password is not written down, it has been found that passwords can often be easily guessed if the users are permitted to pick their own passwords.

To demonstrate how easy it is to guess a user's password, the Multics password list obtained from the decryption effort was sampled. The following approximate percentages of "easily guessed" passwords were observed:

Total Passwords Sampled:	325
Directly Associable	100 - (31%)
Common English Words	50 - (15%)
Short (3 letters or less)	20 - (6%)
Total Easily Guessed:	170 (52%)

The category of passwords directly associable with the person covered two types of associations. Names, both personal and project, were one type used to provide associable passwords. These passwords consisted of initials, first names, reversed spelling, friend's names, etc. Numbers, such as telephone numbers and social security numbers, were the second type used as directly associable passwords. Combinations of associable names and numbers were also observed.

Based on this quick analysis, the conclusion is that if users are permitted to provide their own passwords, the work required to "guess" a password is highly likely to be minimal.

Not letting users pick their own passwords is one way to minimize the possibility of having a user's password compromised. <GAS75> describes an algorithm for generating

random pronounceable passwords. By generating pronounceable passwords, the algorithm produces a password the user is more likely to remember, thus minimizing the need for the user to write it down.

Another technique using one-time passwords is described in <RIC73>. Under this scheme, a user's password is changed every time the user logs into the system. In this way, obtaining a user's password is of less value since it may have been changed before the penetrator attempts to log on. It also serves to alert a user if his password has been compromised.

Despite these drawbacks, use of a properly constructed one-way enciphering algorithm can provide a measure of additional security to a system at very little cost. It can provide security against anyone obtaining a password list through an accidental dump of the system files, for example. It will also discourage a system administrator from thinking that in order to be responsible to his duties, he needs to keep a listing of passwords in his office.

The development of an "irreversible" cipher transformation for encrypting passwords is harder than it would appear at first. The Multics algorithm appears to have been selected in an ad hoc fashion. Even so, to the casual observer, it would at first glance appear to be quite difficult to invert.

It is interesting to observe the two approaches embodied in <EVA74> and <PUR74>; one which creates complex ad hoc algorithms, the behavior of which are not known, the other which adopts an analytical approach to the design of the algorithm and computes the probability of successful attack under stated assumptions regarding what is known or assumed available to the attacker.

For future developments in this area, one or more of the functions discussed by Evans appears more promising than the function which had been used on Multics. ESD/MCI has provided an improved password scrambler that is now used in Multics although the "non-invertibility" of it is not guaranteed. This routine is also used in Multics to encrypt and decrypt files. The basic encryption algorithm is contained in Appendix D.

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APPENDIX A
Password Scramble Listing

This appendix contains the listing of "scramble_," the program used on Multics at the time of the ESD security study to encipher user passwords. This routine was invoked at every user login attempt. It enciphered the password typed at the terminal for comparison with the version of the password stored in the Person Name Table. As a result of the ESD security analysis, an improved password enciphering algorithm is now in use on Multics. This improved algorithm is listed in Appendix D.

```
scramble_: proc (arg) returns (char (8) aligned);

/* SCRAMBLE_ - Scramble a char (8) string.


   This procedure, given a password as input, returns an 8-character
   output string which:
   1. bears some relationship to the input
   2. loses some information - some passwords may scramble to the same value
   3. has no obvious relation to the input ("aaaaaaaa" and "aaaaaaab"
      scramble to noticeably different values.)


   Passwords stored in system files are scrambled, so that if anyone gets
   a dump of the password file by accident, it won't do him much good.


   The transform is supposed to be non-invertible. I am not sure it is.


   Method:
   1. strip the two high-order bits of each ASCII character, packing to
      the right.
   2. treat the resulting 56-bit quantity as an integer (note that it is
      positive). multiply this number by the low-order 16 bits of itself.
   3. divide the resulting product by 10**19-1 and return the remainder.


   THVV 10/30/71
    */
```

```
dcl   arg char (8) aligned;

dcl   temp char (8),
      templ fixed bin (71),
     (p1,p2) ptr,                                  /* ptrs to based overlays */
     (i,k) fixed bin;

dcl   bbt bit (72) aligned based (p1),
      bc8 char (8) aligned based (p2);

dcl  1 tsx based (p2) aligned,
     2 pad bit (16) unal,
     2 z (8) bit (7) unal;

dcl  1 tsy based (p2) aligned,
     2 pad bit (56) unal,
     2 b16 bit (16) unal;

dcl   const fixed bin (71) int static init (99999999999999999);

dcl  (addr, fixed, mod, substr) builtin;

/* ------------------------------------------------------- */

      temp = arg;                                  /* copy argument */
      p1 = addr (temp);
      p2 = addr (templ);
      templ = 0;
      k = 1;
      do i = 3 to 72 by 9;
           z(k) = substr (bbt, i, 7);              /* squeeze out always-zero bits */
           k = k + 1;
      end;
      templ = templ * fixed (b16,16);              /* sort of square the number */
      templ = mod (templ, const);
      return (bc8);

end;
```

APPENDIX B
Unscrambling Listing for Short Passwords

This appendix contains the listing of "unscr," the unscrambling routine used to invert enciphered passwords of less than or equal to six characters. This routine is discussed in section II. When unscr is applied to a password that has been enciphered by scramble_, it will either return a recovered password, or it will report a failure if the password is more than six characters long.

```
print unscr.pl1

                    unscr.pl1 10/24/72  1020.0 edt Tue


 unscr:
     proc (r, a, v) returns (bit (1) aligned);
          dcl
               c fixed bin (71) aligned init (999999999999999999) int static,
              (     r,
                    a,
                    q,
                    t,
                    v,
                    w,
                    h)
               fixed bin (71),
               pp ptr;
          dcl
              (     sysprint,
                    sysin)
               file;
          dcl
               1 bits based (pp) aligned,
                    2 pad bit (56) unal,
                    2 b16 bit (16) unal;
          h = 10000000000000000b * (10000000000000000000000000000000000000000b*a - a) + a*a;
          h = divide (h, c, 71, 0) + 1;
          do q = 0 to h;
               if mod (q, 1000) = 0 then put data (q);
               t = c*q +r;
               if mod (t, a) = 0 then
                    do;
                         v = divide (t, a, 71, 0);
                         w = v - a;
                         pp = addr (w);
                         if b16 = "0"b then return ("1"b);
                    end;
          end;
          return ("0"b);
     end unscr;
```

APPENDIX C
General Unscrambling Listing for All Passwords

This appendix contains the listing of "better", the routine which was used to successfully invert all passwords in the Person Name Table. The nature of the general solution is discussed in section III.

```
ASSEMBLY LISTING OF SEGMENT >udd>Multics>better.alm
ASSEMBLED ON:       12/22/72  0903.2 est Fri
OPTIONS USED:       list  symbols  new_call  new_object
ASSEMBLED BY:       ALM Version 4.1, November 1972
ASSEMBLER CREATED:  12/14/72  0612.4 est Thu

 000000                               1             name better
 000000            000000             2             entry    better
                                      3             temp     lost_bit
                                      4             tempd    someplace
                                      5             tempd    dividend
                                      6             tempd    odiv
                                      7             tempd    linkptr
 000000                               8   better:
 000000  aa   000140 6270 00          9             push
 000001  aa 7 00040 2721 20
 000002  aa 0 00002 2371 20          10             ldaq     ap|2,*     "copy input argument
 000003  aa 0 00006 3521 20          11             eapbp    ap|6,*     "pointer to pointer to index table
 000004  aa 2 00000 3521 20          12             eapbp    bp|0,*     "pointer to index table in bp
 000005  aa 0 00010 3701 20          13             eaplp    ap|8,*     "pointer to pointer to value table
 000006  aa 4 00000 3701 20          14             eaplp    lp|0,*     "pointer to value table in lp
 000007  aa 6 00060 6501 00          15             stplp    linkptr    "saved value of value table ptr
 000010  aa 6 00050 4501 00          16             stz      lost_bit   "initialize to positive product
 000011  aa   000022 7100 00         17             tra      bl_entry
                                     18
 000012                              19   big_loop:
 000012  aa 6 00056 2371 00          20             ldaq     odiv
 000013  aa   000146 0370 00         21             adlaq    modulus
 000014  aa   000022 6050 00         22             tpl      bl_entry   "if no overflow to sign bit, keep trying
 000015  aa 6 00050 2261 00          23             ldx6     lost_bit   "else get pass indicator
 000016  aa   000135 6010 00         24             tnz      error_return        "if positive we've tried it all
 000017  aa   400000 2660 03         25             orx6     =o400000,du         "else mask for a negative product
 000020  aa 6 00050 7461 00          26             stx6     lost_bit   "to use in loops
 000021  aa 0 00002 2371 20          27             ldaq     ap|2,*     "and reinitialize adding loop
 000022                              28   bl_entry:
 000022  aa 6 00056 7571 00          29             staq     odiv
 000023  aa   216000 4110 03         30             lde      =71b25,du  "normalizing exponent to e
 000024  aa   400000 4750 03         31             fad      =0.,du     "add zero to float odiv
 000025  aa 6 00052 4571 00          32             dfst     someplace  "floated version of dividend
 000026  aa   000142 5670 00         33             dfdv     fmod       "divide by floating version of 10**19-1
 000027  aa   000140 4770 00         34             dfad     k71b25     "add magic number to make integer
 000030  aa   000142 4630 00         35             dfmp     fmod       "multiply back to get mod
 000031  aa   000000 5130 00         36             fneg                "set to subtract from odiv
 000032  aa 6 00052 4771 00          37             dfad     someplace  "subtract
 000033  aa   216000 4350 03         38             ufa      =71b25,du  "fix remainder
 000034  aa 0 00002 1171 20          39             cmpaq    ap|2,*     "compare against input
 000035  aa   000012 6010 00         40             tnz      big_loop   "if different, no inner loop
 000036  aa 6 00052 2351 00          41             lda      someplace  "else get precision loss
 000037  aa   000012 7710 00         42             arl      10         "exponent to index alignment
 000040  aa   777701 6240 01         43             eax4     -63,au     "reduce by no-loss precision and put in x4
 000041  aa   000043 6050 00         44             tpl      set_ones   "and go mask dividend
 000042  aa   000000 6240 00         45             eax4     0          "no loss of precision
 000043                              46   set_ones:
 000043  aa 6 00056 2371 00          47             ldaq     odiv
 000044  aa   000161 2750 14         48             orq      set_ones_table,4     "make lost bits in dividend ones
 000045  aa 6 00050 2751 00          49             ora      lost_bit   "restore lost bit from multiply
 000046  aa 6 00054 7571 00          50             staq     dividend
 000047  aa   000000 6200 05         51             eax0     0,al
 000050  aa   000000 6210 06         52             eax1     0,ql       "lower dividend in x0 and x1
 000051  aa   000172 3760 14         53             anq      mask_table,4         "adjust range of sqrt scan for precision loss
 000052  aa   000161 7230 14         54             lxl3     set_ones_table,4     "number of squares resulting from precision l
```

```
000053  aa   000000 6270 06    55          eax7    0,ql        "square in x7
000054  0a   000060 7100 00    56          tra     mid_loop_entry      "go start working on squares
000055                          57  mid_loop:
000055  aa   777777 6230 13    58          eax3    -1,3        "count squares processed
000056  0a   000012 6040 00    59          tmi     big_loop    "if done go to outer loop
000057  aa   000001 0270 17    60          eax7    1,7         "else do next square
000060                          61  mid_loop_entry:
000060  aa   2 00000 7251 17    62          lxl5    bp|0,7      "get count of roots for this square
000061  0a   000055 6000 00    63          tze     mid_loop    "if none get next square
000062  aa   6 00060 3701 20    64          eaplp   linkptr,*   "get lp pointer to base of value segment
000063  aa   2 00000 2261 17    65          ldx6    bp|0,7      "get disp to first root
000064  aa   5 00100 3701 16    66          eaplp   lp|0,6      "and pointer to it in lp
                                67
000065                          68  loop:
000065  aa   777777 5250 15    69          eax5    -1,5        "decrement square root count
000066  0a   000055 6040 00    70          tmi     mid_loop    "done when negative
000067  aa   6 00054 2361 00    71          ldq     dividend    "get first 18 bits of dividend
000070  aa   000022 7720 00    72          qrl     18
000071  aa   4 00000 5061 15    73          div     lp|0,5      "divide by trial root
000072  aa   000030 0360 10    74          eaq     0,0         "next 18 bits
000073  aa   000022 7330 00    75          lrs     18          "set up with remainder
000074  aa   4 00000 5061 15    76          div     lp|0,5
000075  aa   6 00055 2361 00    77          ldq     dividend+1          "get lower dividend upper half
000076  aa   000022 7330 00    78          lrs     18          "add previous remainder
000077  aa   4 00000 5061 15    79          div     lp|0,5
000100  aa   000000 0360 11    80          eaq     0,1         "get rest of lower dividend word
000101  aa   000022 7330 00    81          lrs     18
000102  aa   4 00000 5061 15    82          div     lp|0,5
000103  0a   000150 3150 14    83          cana    compare_table,4     "check for almost zero remainder
000104  0a   000065 6010 00    84          tnz     loop        "if non-zero, try again
                                85
000105  aa   000000 6260 06    86          eax6    0,ql        "save quotient in X6
000106  aa   4 00000 1361 15    87          shlq    lp|0,5
000107  aa   177777 3160 07    88          canq    65535,dl    "mod 2**16
000110  0a   000065 6010 00    89          tnz     loop        "try again if not 0 mod
                                90
000111  aa   6 00054 2361 00    91          ldq     dividend    "get quotient
000112  aa   000022 7720 00    92          qrl     18
000113  aa   4 00000 5061 15    93          div     lp|0,5
000114  aa   000000 6220 06    94          eax2    0,ql
000115  aa   777774 3020 03    95          canx2   =o777774,du
000116  0a   000065 6010 00    96          tnz     loop
                                97
000117  aa   0 00004 3521 20    98          eapbp   ap|4,*      "make bp point to output destination
000120  aa   2 00600 7421 00    99          stx2    bp|0
000121  aa   000000 0360 10   100          eaq     0,0
000122  aa   000022 7330 00   101          lrs     18
000123  aa   4 00000 5061 15   102          div     lp|0,5      "not previously
000124  aa   000000 6220 06   103          eax2    0,ql
000125  aa   2 00000 6421 00   104          sxl2    bp|0        "saved in loop
000126  aa   6 00055 2361 00   105          ldq     dividend+1          "and store
000127  aa   000022 7330 00   106          lrs     18
000130  aa   4 00000 5061 15   107          div     lp|0,5      "in bp|0
000131  aa   000000 6250 05   108          eax5    0,ql
000132  aa   2 00001 7451 10   109          stx5    bp|1        "return quotient
000133  aa   2 00001 4461 00   110          sxl6    bp|1
                               111
000134                         112  return:
000134  aa   7 00042 7101 20   113          return
                               114
                               115
000135                         116  error_return:
000135  0a   000144 2370 00   117          ldaq    minus_one
000136  aa   0 00004 7571 20   118          staq    ap|4,*
000137  0a   000134 7100 00   119          tra     return
```

```
                                    121   "
                                    122   "         DATA
                                    123   "
                                    124             even
000140  aa   216000 000000          125   k71625:   oct       216000000000,000000000000
000141  aa   000000 000000
000142  aa   200425 434430          126   fool:     oct       200425434430,110474777777
000143  aa   110474 777777
000144                              127   minus_one:
000144  aa   777777 777777          128             dec       -1
000145  aa   777777 777777          129             dec       -1
                                    130
000146                              131   modulus:  "(10**19)-1-1
000146  aa   001053 071060          132             oct       001053071060
000147  aa   221171 777776          133             oct       221171777776
000150                              134   compare_table:
000150  aa   777777 777777          135             oct       777777777777
000151  aa   777777 777776          136             oct       777777777776
000152  aa   777777 777774          137             oct       777777777774
000153  aa   777777 777770          138             oct       777777777770
000154  aa   777777 777760          139             oct       777777777760
000155  aa   777777 777740          140             oct       777777777740
000156  aa   777777 777700          141             oct       777777777700
000157  aa   777777 777600          142             oct       777777777600
000160  aa   777777 777400          143             oct       777777777400
000161                              144   set_ones_table:
000161  aa   000000 000000          145             oct       0
000162  aa   000000 000001          146             oct       1
000163  aa   000000 000003          147             oct       3
000164  aa   000000 000007          148             oct       7
000165  aa   000000 000017          149             oct       17
000166  aa   000000 000037          150             oct       37
000167  aa   000000 000077          151             oct       77
000170  aa   000000 000177          152             oct       177
000171  aa   000000 000377          153             oct       377
000172                              154   mask_table:
000172  aa   000000 177777          155             oct       177777
000173  aa   000000 177776          156             oct       177776
000174  aa   000000 177774          157             oct       177774
000175  aa   000000 177770          158             oct       177770
000176  aa   000000 177760          159             oct       177760
000177  aa   000000 177740          160             oct       177740
000200  aa   000000 177700          161             oct       177700
000201  aa   000000 177600          162             oct       177600
000202  aa   000000 177400          163             oct       177400
                                    164
                                    165             end
```

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```
ENTRY SEQUENCES

000203  5a   000010 0000 00
000204  aa   7 00046 2721 20
000205  0a   000000 7100 00

NO LITERALS

NAME DEFINITIONS FOR ENTRY POINTS AND SEGDEFS

000206  5a   000003 000000
000207  aa   000000 000000
000210  aa   000003 000000
000211  55   000011 000002
000212  5a   000002 400003
000213  55   000006 000010
000214  aa   006 142 145 154
000215  aa   154 145 162 000
```

```
000217  aa   000204 000000
000220  55   010113 000005
000221  aa   066 142 145 154          better
000222  aa   164 145 122 000
000223  55   000002 000011
000224  aa   000000 000002
000225  55   000020 000003
000226  aa   116 163 171 155          . symbol_table
000227  aa   142 157 154 137
000230  aa   164 141 142 154
000231  aa   145 060 063 000
```

NO EXTERNAL NAMES

NO TRAP POINTER WORDS

TYPE PAIR BLOCKS

```
000232  aa   000001 000000
000233  aa   000000 000000
```

INTERNAL EXPRESSION WORDS

COMPILER INFORMATION

```
000000  aa   000000 000000
000001  0a   000206 000000
000002  aa   000000 000000
000003  aa   000000 000000
000004  aa   000000 000000
000005  aa   000000 000000
000006  22   000010 000010
000007  a2   000000 000010
```

SYMBOL INFORMATION

SYMBOL TABLE HEADER

```
000000  aa   000300 000001
000001  aa   163171 155142
000002  aa   164162 145145
000003  aa   000030 000004
000004  aa   000000 100422
000005  aa   031241 730745
000006  aa   000000 100434
000007  aa   206142 401614
000010  aa   141154 155040
000011  aa   040040 040040
000012  aa   000024 000040
000013  aa   000034 000040
000014  aa   000044 000100
000015  aa   000002 000002
000016  aa   000064 000000
000017  aa   000000 000130
000020  aa   000000 000102
000021  aa   000000 000117
000022  aa   000122 000102
000023  aa   000064 000000
000024  aa   101114 115040
000025  aa   126145 162163
000026  aa   151157 156040
000027  aa   064056 061054
000030  aa   040116 157166
000031  aa   145155 142145
000032  aa   162060 061071
000033  aa   067062 040040
```

```
000034  aa  115141 162167
000035  aa  145162 050104
000036  aa  062165 051144
000037  aa  056141 040040
000040  aa  040040 040040
000041  aa  040040 040040
000042  aa  040040 040040
000043  aa  040040 040040
000044  aa  154151 163164
000045  aa  040040 163171
000046  aa  155142 157154
000047  aa  163040 040156
000050  aa  145167 137143
000051  aa  141154 154040
000052  aa  040156 145167
000053  aa  137157 142152
000054  aa  145143 164040
000055  aa  040040 040040
000056  aa  040040 040040
000057  aa  040040 040040
000060  aa  040040 040040
000061  aa  040040 040040
000062  aa  040040 040040
000063  aa  040040 040040
000064  aa  000000 000001
000065  aa  000000 000001
000066  aa  000072 000037
000067  aa  004341 171504
000070  aa  000000 100434
000071  aa  200151 000000
000072  aa  076160 154144      >pdd>[BDqGFzfGGBBBGGB>better.alm
000073  aa  076041 102104
000074  aa  161102 105172
000075  aa  154102 102102
000076  aa  102102 102102
000077  aa  076142 145164
000100  aa  164145 162056
000101  aa  141154 155040
```

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(114 MULTICS ASSEMBLY CROSS REFERENCE LISTING

Value	Symbol	Source file	Line number
0	better	better:	2, 8.
12	big_loop	better:	19, 40, 59.
22	bl_entry	better:	17, 22, 28.
150	compare_table	better:	83, 134.
56	divi lend	better:	5, 50, 71, 77, 91, 105.
135	error_return	better:	24, 116.
142	fend	better:	33, 35, 120.
140	671b25	better:	34, 125.
60	linkptr	better:	7, 15, 64.
65	loop	better:	68, 84, 89, 96.
50	lost_bit	better:	3, 16, 23, 26, 49.
172	mask_table	better:	53, 154.
55	mid_loop	better:	57, 63, 70.
69	mid_loop_entry	better:	56, 61.
144	minus_one	better:	117, 127.
146	modulus	better:	21, 131.
56	mqlv	better:	6, 20, 29, 47.
134	return	better:	112, 119.
53	set_ones	better:	44, 46.
161	set_ones_table	better:	48, 54, 144.
52	someplace	better:	4, 32, 37, 41.

APPENDIX D
Improved Password Scrambling Listing and Documentation

This appendix contains the listing of "encipher_", the improved password scrambling algorithm which was implemented on Multics following the ESD security analysis. This program is also used to encrypt and decrypt files in Multics using the standard Multics commands "encode" and "decode".

The algorithm generates a new key word by forming a function selection word from the last ciphertext word (or initial key at the start), then using the last ciphertext word as a fill, generates a new key word according to bits 0-4 of the function selection word as shown in the table below. The notation used in the table is:

- ⓓ rotate function (circular shift the value on the right by the amount on the left)
- + addition
- ⊕ exclusive OR

The expressions are evaluated from right to left with parenthetic grouping having its normal meaning. As an example, the expression M5 + A5 ⓓ (M4 ⊕ M3 + A3 ⓓ (M2 ⊕ M1 + A1 ⓓ C)) would be evaluated as

a) Rotate C by the amount A1
b) Add M1
c) Exclusive OR M2
d) Rotate the value obtained thus far by the amount A3
e) Add M3
f) Exclusive OR M4
g) Rotate the value obtained thus far by the amount A5
h) Add M5

The values of M1, ..., M7 and A1, ..., A7 are offsets in the register containing the key. The contents of this register are obtained by applying a Tausworth pseudo-random number generator (1) to the input key value. The value of C is the word that is to be enciphered.

Figure 4 is a flowchart for the portion of encipher_ that actually performs the enciphering of a word.

---

(1) Whittleself, John R.B., "A Comparison of the Correlation Behavior of Random Number Generators for the IBM 360", Communications of the ACM, Vol 11, No. 9, September 1968.

Function Select = 0-4 of M7 ⊕ A7 ⊞ (M6 + A6 ⊞ C(i-1))

BITS 0-4 OF FUNCTION SELECT (bits numbered 4, 3, 2, 1)	KEY GENERATING FUNCTION
0000	M5 + A5 ⊞ (M4 ⊕ A4 ⊞ (M3 + A3 ⊞ (M2 ⊕ A2 ⊞ (M1 + A1 ⊞ C))))
0001	M5 + M4 ⊕ A4 ⊞ (M3 + A3 ⊞ (M2 ⊕ A2 ⊞ (M1 + A1 ⊞ C)))
0010	M5 + A5 ⊞ (M4 ⊕ M3 + A3 ⊞ (M2 ⊕ A2 ⊞ (M1 + A1 ⊞ C)))
0011	M5 + M4 ⊕ M3 + A3 ⊞ (M2 ⊕ A2 ⊞ (M1 + A1 ⊞ C))
0100	M5 + A5 ⊞ (M4 ⊕ A4 ⊞ (M3 + M2 ⊕ A2 ⊞ (M1 + A1 ⊞ C)))
0101	M5 + M4 ⊕ A4 ⊞ (M3 + M2 ⊕ A2 ⊞ (M1 + A1 ⊞ C))
0110	M5 + A5 ⊞ (M4 ⊕ M3 + M2 ⊕ A2 ⊞ (M1 + A1 ⊞ C))
0111	M5 + M4 ⊕ M3 + M2 ⊕ A2 ⊞ (M1 + A1 ⊞ C)
1000	M5 + A5 ⊞ (M4 ⊕ A4 ⊞ (M3 + A3 ⊞ (M2 ⊕ M1 + A1 ⊞ C)))
1001	M5 + M4 ⊕ A4 ⊞ (M3 + A3 ⊞ (M2 ⊕ M1 + A1 ⊞ C))
1010	M5 + A5 ⊞ (M4 ⊕ M3 + A3 ⊞ (M2 ⊕ M1 + A1 ⊞ C))
1011	M5 + M4 ⊕ M3 + A3 ⊞ (M2 ⊕ M1 + A1 ⊞ C)
1100	M5 + A5 ⊞ (M4 ⊕ A4 ⊞ (M3 + M2 ⊕ M1 + A1 ⊞ C))
1101	M5 + M4 ⊕ A4 ⊞ (M3 + M2 ⊕ M1 + A1 ⊞ C)
1110	M5 + A5 ⊞ (M4 ⊕ M3 + M2 ⊕ M1 + A1 ⊞ C)
1111	M5 + M4 ⊕ M3 + M2 ⊕ M1 + A1 ⊞ C

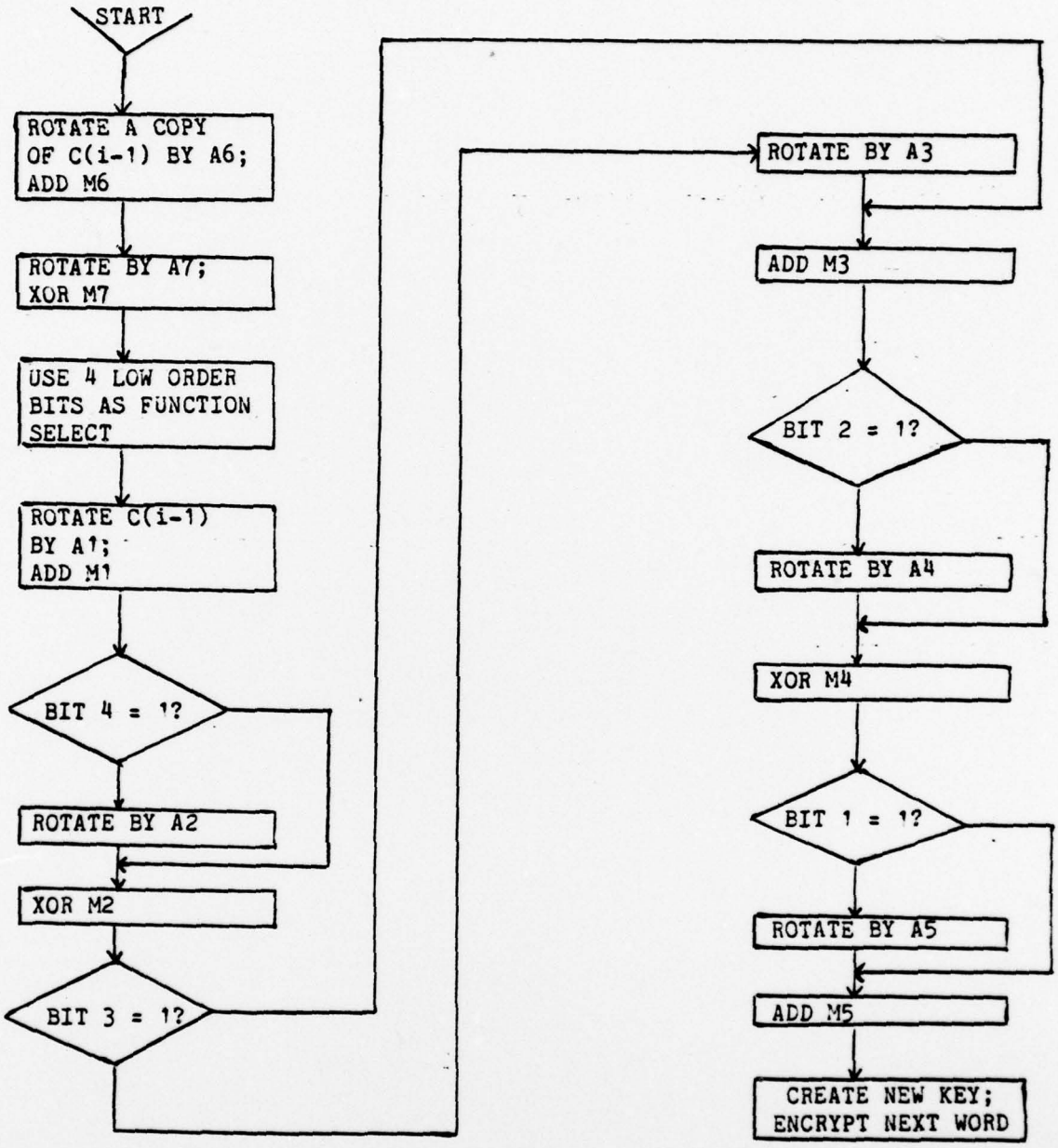

FIGURE 4. Flowchart for encipher_.

```
ASSEMBLY LISTING OF SEGMENT >udd>SDruid>Austell>encipher_.alm
ASSEMBLED ON:        05/09/75  1642.2 edt Fri
OPTIONS USED:        is  symbols  new_call  new_object
ASSEMBLED BY:        ALM Version 4.5, September 1974
ASSEMBLER CREATED:   04/29/75  1343.9 edt Tue

                           """"""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""
                           " This procedure enciphers an arrya of double words, i.e., fixed bin(71),
                           " using the key that is provided.  It has entries to both encipher and decipher:
                           "
                           "          call encipher_(key,input_array,output_array,array_length)
                           "
                           "          call decipher_(key,input_array,output_array,array_length)
                           "
                           " where:   key                 is fixed bin(71) key for coding
                           "          input_array(array_length) is fixed bin(71) array
                           "          output_array(array_length) is fixed bin(71) array
                           "          array_length        is fixed bin(17) length (double words) of array
                           "
                           "          Coded 1 April 1973 by Roger R. Schell, Major, USAF
                           """"""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""

000000                                followon
000000           000000               entry     encipher_
000000           000004               entry     decipher_

000000           000002               equ       key,2
000000           000004               equ       input_array,4
000000           000006               equ       output_array,6
000000           000010               equ       array_length,8

                           "
                           "          Entry to encipher
                           "

000000                     encipher_:
000000  aa   000100 6270 00           push
000001  aa  7 00040 2721 20
000002  aa  0 00006 3701 20           epplp     ap|output_array,*    "LP -> cipher text
000003  0a   000007 7100 00           tra       setup_keys

                           "
                           "          Entry to decipher
                           "

000004                     decipher_:
000004  aa   000100 6270 00           push
000005  aa  7 00040 2721 20
000006  aa  0 00004 3701 20           epplp     ap|input_array,*     "set LP -> cipher text

000007                     setup_keys:
                                                                     "First create internal keying variables
                           "Use Tausworth pseudo-random number generator on key

000007           000013               equ       shift,11             "Shift for generator
000007           000044               equ       size,36              "Word size used for generator

                                      tempd     variables(12)        "Internal keying variables

000007  aa   000000 6260 00           eax6      0                    "loop index in x6
```

```
000010  aa  0 00002 2371 20    53              ldaq    apikey,*        "Start with input key
                               54
000011                         55  mask_loop1
                               56                                      "Create masks
000011  aa  6 00050 7571 16    57              staq    variables,6     "save copy of generator seed
000012  aa    000013 7720 00    58              qrl     shift           "Now generate pseudo-random number
000013  aa    000013 7710 00    59              arl     shift
000014  aa  6 00050 6771 16    60              eraq    variables,6
000015  aa  6 00050 7571 16    61              staq    variables,6
000016  aa    000031 7360 00    62              qls     size-shift
000017  aa    000031 7350 00    63              als     size-shift
000020  aa  6 00050 6771 16    64              eraq    variables,6
000021  aa  6 00050 7571 16    65              staq    variables,6     "Save result
                               66
000022  aa    000002 6260 16    67              eax6    2,6
000023  aa    000022 1060 03    68              cmpx6   18,du          "Generate 9 double words
000024  0a    000011 6010 00    69              tnz     mask_loop
                               70
                               71  "
                               72  "Next create 7-bit shift variables
                               73
000025  aa    000000 6260 00    74              eax6    0
000026  aa    000013 7730 00    75              lrl     11              "First 7 bits to upper A-reg
000027  aa    000000 6200 00    76              eax0    0               "Zero for clearing half word
000030                         77  shift_loop1
000030  aa  6 00070 7551 16    78              sta     variables+A1,6  "Upper A-reg is shift variable
000031  aa  6 00070 4401 16    79              sxl0    variables+A1,6  "Zero lower half word
000032  aa    000007 7370 00    80              lls     7
000033  0a    000116 3750 00    81              ana     =o000177777777  "Save 7 bits in upper A-reg
000034  aa    000001 6260 16    82              eax6    1,6
000035  aa    000007 1060 03    83              cmpx6   7,du            "Generate 7 shift variaties
000036  0a    000030 6010 00    84              tnz     shift_loop
                               85
                               86  "
                               87  "       Now that we have needed variables, aply the cipher
                               88  "
                               89
                               90  "Declaration of offsets of keying variables
000037                 000000  91              equ     C0,0            "Initial cipher text from key
000037                 000002  92              equ     M1,2            "Mask variables
000037                 000004  93              equ     M2,4
000037                 000006  94              equ     M3,6
000037                 000010  95              equ     M4,8
000037                 000012  96              equ     M5,10
000037                 000014  97              equ     M6,12
000037                 000016  98              equ     M7,14
000037                 000020  99              equ     A1,16           "Amount of shift -- as address
000037                 000021 100              equ     A2,17
000037                 000022 101              equ     A3,18
000037                 000023 102              equ     A4,19
000037                 000024 103              equ     A5,20
000037                 000025 104              equ     A6,21
000037                 000026 105              equ     A7,22
                              106
000037  aa  0 00010 7251 20   107              lxl5    aplarray_length,*  "Get length (double words)
000040  aa   777777 6250 15   108              eax5    -1,5            "Check for zero or negative
000041  0a    000103 6040 00   109              tmi     return
000042  aa    000000 6260 00   110              eax6    0               "X6 is index into arrays
000043  aa  6 00050 3521 00   111              eppbp   variables+C0    "Initial cipher text from key
000044                        112  cipher_loop1
```

```
000044  aa  2 00000 2371 00   113              ldaq      bpl0
                               114
                               115   "First compute select function
                               116
000045  aa  6 00075 7771 20   117              llr       variables+A6,*
000046  aa  6 00064 0371 00   118              adlaq     variables+M6
000047  aa  6 00076 7771 20   119              llr       variables+A7,*
000050  aa  6 00066 6771 00   120              eraq      variables+M7
000051  aa   000000 6210 06   121              eaxi      0,qi                "Save select function
                               122   "
                               123   "Compute value
                               124   "
000052  aa  2 00000 2371 00   125              ldaq      bpl0
000053  aa  6 00070 7771 20   126              llr       variables+A1,*
000054  aa  6 00052 0371 00   127              adlaq     variables+M1
000055  aa   000010 3010 03   128              canxi     =o10,du
000056  aa   000002 6010 04   129              tnz       2,ic
000057  aa  6 00071 7771 20   130              llr       variables+A2,*
000060  aa  6 00054 6771 00   131              eraq      variables+M2
000061  aa   000004 3010 03   132              canxi     =o4,du
000062  aa   000002 6010 04   133              tnz       2,ic
000063  aa  6 00072 7771 20   134              llr       variables+A3,*
000064  aa  6 00056 0371 00   135              adlaq     variables+M3
000065  aa   000002 3010 03   136              canxi     =o2,du
000066  aa   000002 6010 04   137              tnz       2,ic
000067  aa  6 00073 7771 20   138              llr       variables+A4,*
000070  aa  6 00060 6771 00   139              eraq      variables+M4
000071  aa   000001 3010 03   140              canxi     =o1,du
000072  aa   000002 6010 04   141              tnz       2,ic
000073  aa  6 00074 7771 20   142              llr       variables+A5,*
000074  aa  6 00062 0371 00   143              adlaq     variables+M5        "AQ contains computed key
                               144
000075  aa  4 00000 3521 16   145              eppbp     ipl0,6              "set BP -> next cipher text autokey
000076  aa  0 00004 6771 76   146              eraq      aplinput_array,*6
000077  aa  0 00006 7571 76   147              staq      aploutput_array,*6  "return ciphered value
000100  aa   000002 6260 16   148              eax6      2,6                 "Increment array offset
000101  aa   777777 6250 15   149              eax5      -1,5                "Check for end of array
000102  0a   000044 6050 00   150              tpl       cipher_loop
000103                         151   return:
                               152   "
                               153   "Clean up the 'dirty blackboard' before returning
                               154
000103              005202     155              bool      rpt,5202            "RPT instruction
                               156
000103  0a   000103 2370 00   157              ldaq      *                   " Load AQ with garbage
000104  aa   000000 6260 00   158              eax6      0
000105  aa   026200 520202     159              vfd       8/11,2/0,1/1,7/0,12/rpt,6/2 "RPT instruction
000106  aa  6 00050 7571 16   160              staq      variables,6         "Overwrite keying variables
                               161
000107  aa  7 00042 7101 20   162              return
                               163
                               164              end
```

ENTRY SEQUENCES

```
000110  5a    000017 0000 00
000111  aa  7 00046 2721 20
000112  0a    000000 7100 00
000113  5a    000011 0000 00
000114  aa  7 00046 2721 20
000115  0a    000004 7100 00
```

LITERALS

000116 aa 000177 777777

NAME DEFINITIONS FOR ENTRY POINTS AND SEGDEFS

```
    000117  5a    000003 000000
    000120  aa    000000 600000
    000121  aa    000000 000000
    000122  55    000011 000002
    000123  5a    000002 400003
    000124  55    000006 000011
    000125  aa  011 145 156 143
    000126  aa  151 160 150 145
    000127  aa  162 137 000 000
    000130  55    000017 000003
    000131  0a    000114 500000
    000132  55    000014 000003
    000133  aa  011 144 145 143          decipher_
    000134  aa  151 160 150 145
    000135  aa  162 137 000 000
    000136  55    000025 000011
    000137  0a    000111 500000
    000140  55    000022 000003
    000141  aa  011 145 156 143          encipher_
    000142  aa  151 160 150 145
    000143  aa  162 137 000 000
    000144  55    000002 000017
    000145  6a    000000 400002
    000146  55    000030 000003
    000147  aa  014 163 171 155          symbol_table
    000150  aa  142 157 154 137
    000151  aa  164 141 142 154
    000152  aa  145 000 000 000
```


NO EXTERNAL NAMES

NO TRAP POINTER WORDS

TYPE PAIR BLOCKS

```
    000153  aa    000001 000000
    000154  aa    000000 000000
```

INTERNAL EXPRESSION WORDS

```
    000155  aa    000000 000000
```

LINKAGE INFORMATION

```
000 000   aa    000000 000000
000 001   0a    000117 000000
000 002   aa    000000 000000
000 003   aa    000000 000000
000 004   aa    000000 000000
000 005   aa    000000 000000
000 006   22    000010 000010
000 007   a2    000000 000010
```

SYMBOL INFORMATION

SYMBOL TABLE HEADER

```
000 000   aa    000000 000001
000 001   aa    163171 155142
000 002   aa    164162 145145
000 003   aa    000000 000004
000 004   aa    000000 102523
000 005   aa    146512 715866
000 006   aa    000000 102537
000 007   aa    733521 472051
000 010   aa    141154 155040
000 011   aa    040040 040040
000 012   aa    000024 000040
000 013   aa    000034 000040
000 014   aa    000044 000100
000 015   aa    000002 000002
000 016   aa    000064 000000
000 017   aa    000000 000124
000 020   aa    000000 000103
000 021   aa    000000 000113
000 022   aa    000116 000103
000 023   aa    000064 000600
000 024   aa    101114 115040
000 025   aa    126145 162163
000 026   aa    151157 156040
000 027   aa    064056 065054
000 030   aa    040123 145160
000 031   aa    164145 155142
000 032   aa    145162 040061
000 033   aa    071067 064040
000 034   aa    101165 163164
000 035   aa    145154 154056
000 036   aa    123104 162165
000 037   aa    151144 056141
000 040   aa    040040 040040
000 041   aa    040040 040040
000 042   aa    040040 040040
000 043   aa    040040 040040
000 044   aa    154163 040040
000 045   aa    163171 155142
000 046   aa    157154 163040
000 047   aa    040156 145167
000 050   aa    137143 141154
000 051   aa    154040 040156
000 052   aa    145167 137157
000 053   aa    142152 145143
000 054   aa    164040 040040
000 055   aa    040040 040040
000 056   aa    040040 040040
000 057   aa    040040 040040
000 060   aa    040040 040040
000 061   aa    040040 040040
000 062   aa    040040 040040
000 063   aa    040040 040040
000 064   aa    000000 000001
000 065   aa    000000 000001
000 066   aa    000072 000041
000 067   aa    025376 657514
```

```
000070   aa    000000 102537
000071   aa    733524 600000
000072   aa    076165 144144
000073   aa    076123 104162
000074   aa    165151 144076
000075   aa    101165 163164
000076   aa    145154 154076
000077   aa    145156 143151
000100   aa    160150 145162
000101   aa    137056 141154
000102   aa    155040 040040
```

>udd>SOruld>Austell>encipher_.alm

MULTICS ASSEMBLY CROSS REFERENCE LISTING

Value	Symbol	Source file	Line number											
20	A1	encipher_1	78.	79.	99.	126.								
21	A2	encipher_1	100.	130.										
22	A3	encipher_1	101.	134.										
23	A4	encipher_1	102.	138.										
24	A5	encipher_1	103.	142.										
25	A6	encipher_1	104.	117.										
26	A7	encipher_1	105.	119.										
10	array_length	encipher_1	24.	107.										
0	C0	encipher_1	91.	111.										
44	cipher_loop	encipher_1	112.	150.										
4	decipher_	encipher_1	19.	39.										
0	encipher_	encipher_1	18.	30.										
4	input_array	encipher_1	22.	41.	146.									
2	key	encipher_1	21.	53.										
2	M1	encipher_1	92.	127.										
4	M2	encipher_1	93.	131.										
6	M3	encipher_1	94.	135.										
10	M4	encipher_1	95.	139.										
12	M5	encipher_1	96.	143.										
14	M6	encipher_1	97.	118.										
16	M7	encipher_1	98.	120.										
11	mask_loop	encipher_1	55.	69.										
6	output_array	encipher_1	23.	32.	147.									
103	return	encipher_1	109.	151.										
5202	rpt	encipher_1	155.	159.										
7	setup_keys	encipher_1	33.	43.										
13	shift	encipher_1	47.	58.	59.	62.	63.							
30	shift_loop	encipher_1	77.	84.										
44	size	encipher_1	48.	62.	63.									
50	variables	encipher_1	50.	57.	60.	61.	64.	65.	78.	79.	111.	117.	118.	119.
			120.	126.	127.	130.	131.	134.	135.	138.	139.	142.	143.	160.

NO FATAL ERRORS

MISSION
OF THE
DIRECTORATE OF COMPUTER SYSTEMS ENGINEERING

The Directorate of Computer Systems Engineering provides ESD with technical services on matters involving computer technology to help ESD system development and acquisition offices exploit computer technology through engineering application to enhance Air Force systems and to develop guidance to minimise R&D and investment costs in the application of computer technology.

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